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Electrical and optical studies of tunneling transport phenomena in Zn(Cd)Se/Zn(Mg)SSe quantum well and superlattice structures

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Resonant-tunneling diodes (RTD) based on wide band-gap II–VI compounds will hardly be able to compete ever with the well known devices based on III–V semiconductors, due to the relatively large effective masses of carriers and small available band offsets. However, comprehensive understanding and proper use of the tunneling effects may result in important improvements and new concepts as regards to the optoelectronics devices like light-emitting diodes and injection lasers operating in the green and blue spectral regions. A particular shortcoming of the previously reported devices has been an enhanced carrier leakage over heterobarriers, resulting from insufficient band offsets of the available bulk materials. It has been recently suggested and experimentally shown that a short-period superlattice (SL) used in the active region of ZnCdSe/ZnSSe/ZnMgSSe separate confinement heterostructure (SCH) lasers instead of the bulk wave-guide layers can significantly improve the electronic confinement [1]. This approach has allowed one to decrease the threshold power density of the room-temperature optically-pumped lasers down to 20 kW/cm² at 490 nm. To extend this approach to injection lasers, further research is needed, aimed at optimization of carrier tunneling transport along the SL axis. Another potential application of II–VI tunneling structures concerns bipolar RTDs which are currently considered to be perspective as high-speed electroluminescence devices [2].

In this paper, we present electrical and optical studies of ZnCdSe/ZnMgSSe/ZnSSe double-barrier resonant-tunneling structures and ZnSSe/Zn(Cd)Se short-period SLs, focusing on their tunneling properties. All the structures are grown by molecular-beam epitaxy (MBE) pseudomorphically to a GaAs(001) substrate. The growth technique and conditions have been reported elsewhere [3]. The SL structures consist of a ZnSSe/ZnCdSe SL surrounded by thick layers of ZnMgSSe quaternary alloy. A wider ZnCdSe quantum well (QW) is embedded in the center of the SL. The Cd content in the ZnCdSe ternary alloy layers vary in different samples from 25% to 0% (pure ZnSe), however, for all the structures the SL parameters were chosen to balance carefully alternating compressive and tensile strains between the ZnCdSe and ZnSSe constituent layers in order to achieve the multilayer structure lattice-matched to a substrate as a whole. A double-barrier (DB) $n - i - n$ resonant tunneling structure contains a 40 Å wide ZnSe QW placed between 45 Å wide ZnMgSSe barriers. The resonant structure is surrounded by the n -type ZnSSe:Cl buffer and contact layers, with 50 Å wide spacers of undoped ZnSSe adjacent to the barriers.

The temperature-dependent continuous wave (cw) and time-resolved (TR) photoluminescence (PL) and PL excitation (PLE) spectra were measured to characterize the

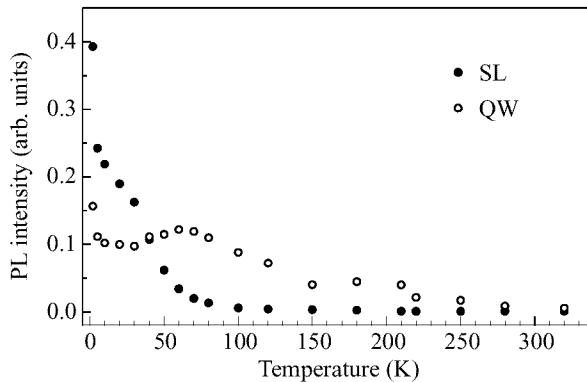


Fig 1.

SL transport properties. The low-temperature PL spectrum excited by the 351 nm line of an Ar ion laser demonstrates two lines comparable in intensity. Both cw PLE spectra and TR PL spectra (measured by streak camera with 15 ps time- resolution) enable one to attribute this lines to excitonic emission in the SL (the higher energy line) and in the wider QW.

Fig. 1 displays integrated intensity of the lines as a function of temperature for the sample containing a 42-period (42 Å — $\text{ZnS}_{0.15}\text{Se}_{0.85}$ / 12 Å — $\text{Zn}_{0.87}\text{Cd}_{0.13}\text{Se}$) SL with an embedded 70 Å — $\text{Zn}_{0.87}\text{Cd}_{0.13}\text{Se}$ QW. The intensity of PL associated with the SL decreases monotonously with the temperature increase and disappears completely at about 100 K. In contrast to that, the dependence for the QW PL is non-monotonous with a peak value at about 70 K. Note that this line is well visible up to room temperature. To explain the PL behavior we calculated the band line-ups and confinement energies in the SL samples. For the sample of Fig. 1 the calculated miniband widths are 72 meV, 9 meV and 104 meV for electrons, heavy holes and light holes, respectively. The lowest heavy-hole exciton is essentially localized in the SL wells due to the low heavy-hole mobility along the SL axis, which explains the dominant intensity of the SL PL at low temperatures. However, the bottom of the light-hole miniband in this structure is only 5–10 meV above the top of the heavy-hole one, providing efficient thermal occupation of the light-hole states with the temperature increase. This process is responsible for the enhanced transfer of holes along the growth direction, followed by their capture in the QW and energy relaxation down to the lowest heavy-hole QW level. This agrees well with the temperature-induced increase in the QW PL intensity. At even higher temperatures the QW PL intensity decreases again due to the enhanced contribution of non-radiative recombination channels. This interpretation is also confirmed by measuring the PL decay time as a function of temperature. The SL PL lifetime decreases drastically down to 30–50 ps at 60–80 K, indicating fast temperature-enhanced tunneling escape. This behavior is generally typical for all the SL samples studied, while the light-hole activation energies reasonably depend on the SL parameters.

Electrical measurements have been performed to proof the unipolar electron resonant tunneling transport in $\text{ZnSe}/\text{ZnMgSSe}/\text{ZnSSe}$ DB heterostructure. Fig. 2 demonstrates a typical 300 K I–V characteristic which involves a pronounced negative-differential-resistance region up to 300 K. Under the dark condition, the excitonic contribution to this

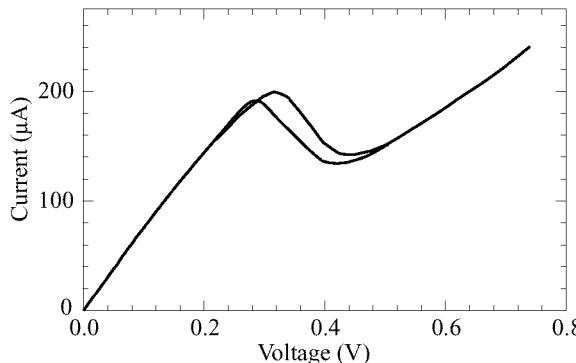


Fig 2.

process is expected to be negligible due to the absence of holes in this unipolar structure. Under illumination, the I-V characteristic changes both due to the light-induced space charge redistribution and the exciton-assisted resonant tunneling [4], however, more detailed experiments are required to separate the two processes.

In summary, we have presented design and studies of ZnSe-based QW tunneling structures grown by MBE, which are potentially suitable for different opto-electronic applications in green and blue spectral regions. The ZnSSe/Zn(Cd)Se SLs are found to be well applicable as highly-transparent hole emitters efficiently operating at 300 K due to the temperature-enhanced transport within the light-hole miniband. A pronounced room-temperature *N*-shaped current-voltage (I-V) characteristic has been reported for the first time for the II-VI wide-bandgap heterostructures that offers a scope for further development of high-frequency optical oscillators and bistable devices.

Acknowledgements

This work has been supported in part by the Russian Foundation for Basic Research and by Program of Ministry of Science of RF “Physics of solid-states nanostructures”.

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